

Chronic Wasting Disease

RECENT TRENDS & IMPLICATIONS IN COLORADO

Maintaining wildlife health is a fundamental component of sound wildlife management and is regarded as a high priority in Colorado. Colorado Parks and Wildlife is dedicated to delivering a coordinated and systematic approach for monitoring, investigating, reporting, and – where feasible – controlling health problems in free-ranging wildlife.

Chronic wasting disease (CWD) is well-established in deer, elk, and moose herds throughout much of Colorado. As of January 2018, 31 of 55 deer data analysis units (DAUs), 14 of 43 elk DAUs, and 2 of 9 moose DAUs have become infected. This prion disease also has been reported in deer, elk, moose, and reindeer (caribou) in 27 other states and provinces, in South Korea, and most recently in Norway.

The rate of CWD infection (or “prevalence”) appears to be rising in many affected Colorado herds. However, trends have become difficult to track in the last 10 years because too few hunters voluntarily submit samples for testing. As a result, our current prevalence estimates for many herds are imprecise and perhaps somewhat biased. In 2017, CPW resumed mandatory harvest submissions in select DAUs. Sample sizes in the targeted DAUs increased 10-fold, yielding better data to inform herd management planning.

Reliable CWD prevalence estimates and trend assessments are needed to inform deer and elk conservation in Colorado. A growing body of data suggests that unchecked CWD epidemics impair the long-term performance of affected populations. Infection shortens the lifespan of deer and elk. On average, animals also become infected at a younger age as epidemics mount. If infection rates become too high, CWD can affect a herd’s ability to sustain itself.

Observed patterns in Colorado suggest cause for both hope and concern. Prevalence in the Red Feather/Poudre Canyon deer herd (D-04) has declined in the decade since CPW applied focal culling and increased harvest in the early 2000s (Figure). Relatively aggressive buck and doe harvest may be helping to suppress prevalence in the Middle Park deer herd (D-09; Figure). In contrast, prevalence in the White River deer herd (D-07) appears to have markedly increased since 2002 (Figure). Management experiments (e.g., buck:doe ratio manipulations, shift in harvest pressure across seasons) – ideally done in coordination with other

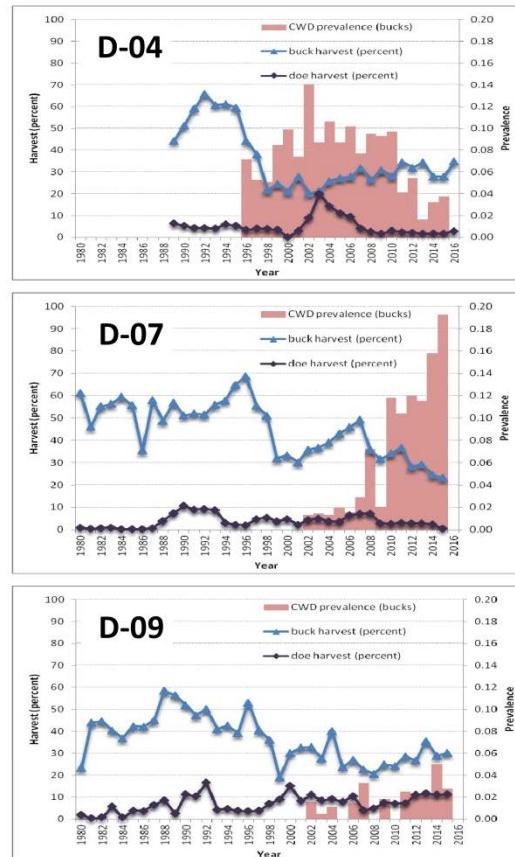


Figure. Chronic wasting disease harvest and prevalence trends in three Colorado mule deer DAUs illustrate patterns and potential relationships between harvest and disease dynamics. A sustained control program was applied to DAU D-04 during 2000– 2005. Harvest rates are expressed as the percentage of estimated bucks and does harvested annually. Prevalence estimated from harvest submissions.

jurisdictions –should be considered in some future DAU plans to help identify and evaluate effective strategies for controlling CWD.

For further reading:

Western Association of Fish and Wildlife Agencies. 2017. Recommendations for Adaptive Management of Chronic Wasting Disease in the West. WAFWA Wildlife Health Committee and Mule Deer Working Group. Edmonton, Alberta, Canada and Fort Collins, Colorado, USA. http://www.wafwa.org/Documents%20and%20Settings/37/Site%20Documents/Committees/Wildlife%20Health/docs/CWDAdaptiveManagementRecommendations_WAFWAfinal_approved010618.pdf

Chronic Wasting Disease



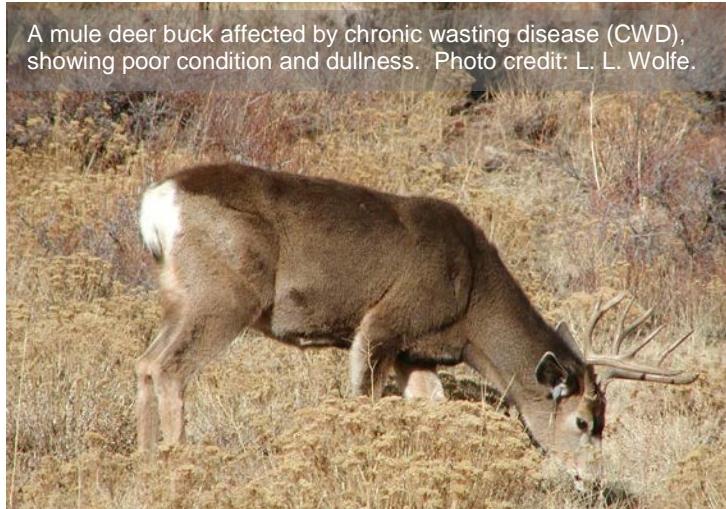
- Chronic wasting disease (CWD) occurs at varying rates of infection in about half of Colorado's deer populations and about one third of the state's elk populations.

Species Affected in Colorado

- Deer, elk, and moose. (Other species in the deer or "cervid" family affected elsewhere.)
- Species outside the deer family appear to have natural resistance to infection.

What to Look For

- Adult deer, elk, or moose that appear to be thin or poor-doing, or that seem to lack awareness or concern or to behave oddly.
- Carcasses of adult deer, elk, or moose that appear to be thin.



Cause & Transmission

Chronic wasting disease is believed to be caused by one or more strains of prion (/prē,ān/; a self-propagating disease agent comprised entirely of protein). Infected deer, elk, and moose shed prions in saliva, feces, urine, and probably by other means. Uninfected animals of susceptible species can be infected by direct exposure or indirectly through prions harbored in soil and perhaps in other reservoirs. Once infected, animals typically survive only 2–3 more years. No immunity develops, and infected animals do not recover.

Implications & Public Health Considerations

In several Colorado deer herds, infection rates among harvested bucks now exceed 10% (1 in 10; see <http://cpw.state.co.us/learn/Maps/CWD-Map-Mule-Deer.pdf>). A growing body of data suggests that unchecked CWD outbreaks impair the long-term performance of affected big game populations. Infection shortens the lifespan of deer and elk. On average, animals also become infected at a younger age as epidemics mount. If infection rates become too high, CWD can affect a herd's ability to sustain itself.

Minimizing human exposure to CWD seems prudent. Although CWD exposure has thus far not been associated with cases of prion disease in humans, public health officials advise against consuming meat or any other tissues from animals known to be infected. As a general rule, hunters should avoid handling carcasses of animals that do not appear to be healthy and report such cases to CPW.

Additional Information/References:

The First Five (or More) Decades of Chronic Wasting Disease: Lessons for the Five Decades to Come. *Transactions of the North American Wildlife and Natural Resources Conference* 81: *in press* (2016). <http://cpw.state.co.us/learn/Pages/ResearchCWD.aspx>

Prion diseases. Colorado Department of Public Health & Environment. <https://www.colorado.gov/pacific/cdphe/prion-diseases>

Recommendations for Adaptive Management of Chronic Wasting Disease in the West



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Suggested citation: Western Association of Fish and Wildlife Agencies. 2017. Recommendations for Adaptive Management of Chronic Wasting Disease in the West. WAFWA Wildlife Health Committee and Mule Deer Working Group. Edmonton, Alberta, Canada and Fort Collins, Colorado, USA.

Approved by the Western Association of Fish & Wildlife Agencies Directors on 6 January 2018

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**Delivering conservation
through information exchange
and working partnerships**

Executive Summary

Chronic wasting disease (CWD) — an infectious prion disease affecting at least four important native cervid species — represents a significant threat to the future health and vitality of free-ranging cervid resources in western North America. Moreover, growing concerns about potential transmissibility to humans could erode hunting participation in affected areas. As this disease continues to spread through free-ranging populations in North America and elsewhere, viable management strategies are needed. This document outlines an approach for experimental application and assessment of prospective CWD suppression strategies using an adaptive management framework. The focus is on mule deer in western prairie, shrub-steppe, and southwest desert systems.

We identify three strategies that warrant further evaluation and provide general guidance on criteria for site selection and evaluation:

Reduce Artificial Points of Host Concentration

Identify consistently available, artificial point-sources of food/minerals/water causing deer to aggregate (e.g., leaky grain bins, grain bags, stack yards, artificial feeders or feeding stations, mineral bins). Work with producers, landowners, and agriculture authorities to mitigate the point source and reduce the density of deer at these point-sources.

Harvest Management

Increase buck harvest, bias harvest toward bucks, and/or shift timing of harvest to post-rut.

Harvest Targeting Disease Foci

Develop a harvest strategy that builds on ongoing (prior) fall harvest programs to maximize removal of infected individuals.

The underlying adaptive management framework includes a systematic approach for learning from management outcomes over time. Results are used to evaluate the hypothesis, but also to gather new data for directing future management. We recommend using a Before-After-Control-Impact (BACI) design. The BACI design identifies matched control and impact (treatment) units, collects the required information prior to applying the treatment, and then monitors the control and treatment units afterwards.

Jurisdictions may employ varied CWD management strategies, but a coordinated effort seems key to long-term success given the required resources and sociopolitical support necessary to address this issue. Ideally, the experimental manipulations described here will be replicated under a core set of standard guidelines with sufficient consistency to facilitate comparisons across jurisdictions. This approach will enhance our collective ability to identify whether and how often a strategy works and the conditions that contribute to its success or failure. The ultimate goal is to provide managers with recommended approaches for reducing CWD prevalence.



Wintering mule deer group

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Introduction

Chronic wasting disease (CWD) — an infectious prion disease affecting at least four important native cervid species — represents a significant threat to the future health and vitality of free-ranging cervid resources in western North America. There is growing evidence that unchecked CWD outbreaks can impair deer and elk population performance. Recent research documents deer declines attributed to CWD in Wyoming (DeVivo 2015, Edmunds et al. 2016), adding to the body of work suggesting that cervid populations suffering high CWD prevalence are not expected to thrive (Miller et al. 2000, 2008, Almberg et al. 2011, Monello et al. 2014, Williams et al. 2014, Galloway et al. 2017). Population impacts appear most readily demonstrated at high prevalence (e.g., >30% in male deer); however, even at lower prevalence affected populations experience added mortality and are likely less resilient with CWD than without. Moreover, growing concerns about potential transmissibility to humans that could erode hunting participation in affected areas provide further incentive for responsible agencies to intervene.

As this disease continues to spread throughout free-ranging populations in North America and elsewhere, viable management strategies are needed. Once CWD has become established in a population (often well before detected), its eradication is not currently considered feasible. Regardless, opportunities remain for responsible management agencies to stabilize or suppress CWD outbreaks and thereby minimize impacts and potentially irreparable harm. Disease control tools such as vaccines, safe and practical agents that can eliminate prions from the environment, or even effective curative therapies remain unavailable. Consequently, to date most attempts to manage CWD have focused on reducing population densities and eliminating areas of CWD foci through a combination of hunter harvest and



agency culling (Blanchong et al. 2006, Conner et al. 2007, Pybus 2012, Mateus-Pinilla et al. 2013, Manjerovac et al. 2014). Many of these programs were prematurely terminated due to lack of early, measurable success, high personnel/agency costs, and lack of public support. Unfortunately, early termination of these programs precluded evaluation of the potential efficacy of longer-term management. This highlights the need for management strategies that include realistic goals, can be applied for extended time periods, and have sufficient public and constituent acceptance. Because eradication is not feasible at this time, management for CWD control will require ongoing commitment by wildlife managers and the public. It follows that programs focused solely on agency culling are unlikely to be viable as a sustained management approach in Western jurisdictions.

Future efforts toward CWD suppression in the West should focus on strategies that exploit or complement current management activities. For example, modeling and some field observations suggest harvest could be used to control CWD (Wild et al. 2011, Jennelle et al. 2014, Geremia et al. 2015, Potapov et al. 2016, Al-Arydah et al. 2016). Male deer appear to have a higher likelihood of CWD infection than females (Miller et al. 2000, Gear et al. 2006, DeVivo et al. 2015). Focusing harvest of sufficient intensity on the segment of the population most likely to be infected could help reduce disease prevalence and subsequent transmission (e.g., Potapov et al. 2016). Exploiting potential biases in removal of infected animals via harvest (e.g., Conner et al. 2000) also could be used to enhance the efficacy of harvest as a control strategy (Wild et al. 2011). For example, targeting mature males via increased harvest pressure during or after the breeding season may selectively remove a higher proportion of infected individuals than harvest in early autumn (Conner et

al. 2000). Such strategies would allow agencies to modify existing harvest management approaches to emphasize CWD suppression and thus should be relatively sustainable in the long-term with minimal additional personnel time or cost.

Alternatively, multiple CWD management programs have targeted winter culling around known CWD-infected animals because of spatial clustering of the disease on the landscape (e.g., Connor et al. 2007, Pybus 2012, Mateus-Pinilla et al. 2013). Data from these management attempts suggest effectiveness in limiting CWD (Pybus 2012, Mateus-Pinilla et al. 2013, Geremia et al. 2015). Due to the poor success in implementing long-term agency culling programs (e.g., Conner et al. 2007, Pybus 2012), an alternative approach might be to use hunting seasons targeting specific winter ranges or disease foci.

Environmental accumulation of prions can contribute to transmission of CWD and may be a significant driver in population response (Almberg et al. 2011). Areas that promote artificial cervid “hotspots” such as mineral licks and artificial feed sources (haystacks, grain bins) may serve as sources of prion concentration and transmission (Miller et al. 2004, Thompson et al. 2008, Lavelle et al. 2014, Mejía-Salazar et al. 2017). Risks associated with intentional winter feeding of cervids, either annually or episodically, also should be considered with respect to exacerbating CWD transmission. Management to reduce or eliminate repeated visitation to spatial concentration points should reduce localized environmental contamination and transmission. Depending on jurisdiction, this approach could require undertaking regulatory and on-the-ground actions. This strategy likely would require significant start-up investments; however, once implemented it could be maintained in the long term at a lower cost.

Despite significant advances in our understanding of CWD over the past 40 years, there is still little published information on effective management (Miller and Fischer 2016, Uehlinger et al. 2016). While some of the aforementioned strategies have been modeled, field data on efficacy are limited or lacking. Nevertheless, wildlife managers are tasked with managing for healthy, sustainable free-ranging populations even in the absence of definitive CWD

control strategies. It follows that a coordinated, adaptive management approach would provide a path forward for CWD management. Adaptive management would allow for strategic application and evaluation of experimental CWD suppression strategies whereby the data gathered would then be used to develop improved strategies. This approach is not to be confused with simple trial and error; rather it is a systematic, hypothesis-based and scientific approach to applied management (Walters 1986, Walters and Holling 1990, Williams 2009). Agencies looking to use an adaptive management approach must be prepared to invest resources into public involvement, communications, data collection, experimental design, and evaluation.

This document outlines an approach for experimental application of select CWD control strategies using an adaptive management framework. We have identified three potential field strategies that warrant further evaluation. We also offer general guidance on criteria for site selection and for evaluation of these strategies. This document is intended to provide guidance on minimum requirements but still allow flexibility for individual agencies to make necessary local decisions. Fully evaluating any individual management strategy would require multiple applications under a variety of intensities and field conditions. As a result, this would be most efficient under a collaborative approach with multiple jurisdictions working together to apply and evaluate management strategies. Each individual agency can elect to apply as many or as few strategies or replicates as appropriate in their jurisdiction, while still gathering valuable data to contribute to broader understanding of CWD control strategies. Due to significant regional differences in habitat, susceptible species, and behavior, we believe such collaboration should be focused at a regional level. This document thus focuses on Western prairie, shrub-steppe, and southwest desert systems where predominantly mule-deer driven epidemiology combined with multiple overlapping susceptible cervid species pose unique challenges for CWD management.

Design Considerations

Ideally, the experimental manipulations described in this document will be replicated under a core set of standard guidelines with sufficient consistency to facilitate comparisons across jurisdictions. This approach will enhance our collective ability to identify whether and how often a strategy works and the conditions that contribute to its success or failure. This document primarily focuses on mule deer, but the approach could be applied to any cervid species thought to be driving local transmission dynamics. If jurisdictions choose to apply these management strategies using a different study design or without meeting minimum criteria for site selection and evaluation then the resulting data may be less useful in regional comparisons and analyses.

Basic design: Before-After-Control-Impact (BACI) Design

Each individual experiment or site should use a Before-After-Control-Impact (BACI) design (Green 1979, Smith 2002). The BACI design identifies matched control and impact (treatment) populations or subunits (e.g., herds; see below), collects the required information prior to applying the treatment, and then monitors the control and treatment afterwards for a predetermined time. Key to this design will be selecting “matching” pairs of herds or units for comparison. The two pair members should be discreet but as similar as possible, with similar habitat conditions, geographic proximity (to control large-scale effects like weather), and similar baseline deer density and age-sex structure, recent past harvest management, and CWD prevalence. The “control” need not be one with no manipulations but with a different treatment; for example, it could be the most common approach to managing mule deer in the jurisdiction, or simply retaining past management practices.

Spatial scale likely will be an important consideration in planning these comparisons. To offer best opportunity to measure treatment effects, the minimum spatial footprint would be a discrete unit that can sustain the proposed manipulation and provide samples sufficient to measure effects of the

manipulation. In some cases, these discrete units might be described by a herd or game management district or unit. In other situations, they may encompass a portion of, or multiple hunt areas, or even an entire population unit.

Minimally, we suggest both control and treatment units be measured for CWD prevalence, aggregating data for up to 3 years prior to treatment to obtain sufficient samples before beginning the experiment. Where feasible, data on deer abundance, age/sex structure, “hot spot” densities, etc., also would be measured and used as the reference conditions prior to treatment(s). Once treatments are initiated, jurisdictions also should plan to measure the efficacy of the intended management treatment (e.g., Was male harvest objective met?). Finally, we suggest measuring CWD prevalence in sympatric cervid species (see Evaluation/Assessment for further elaboration).

Relative CWD Prevalence within Treatment Areas

Prevalence (proportion of sampled animals that are infected) within each prospective management area should be estimated as a basis for comparing to other treatment areas.

- “High prevalence” study areas: treatment and control areas wherein CWD prevalence is $\geq 10\%$ among adult (≥ 2 -year-old) males or females. In these areas, the management goal may be to reduce prevalence or to simply prevent further increase in prevalence.
- “Low prevalence” study areas: treatment and control areas wherein CWD prevalence is $< 10\%$ among adult (≥ 2 -year-old) males or females. In these areas, the primary goal may be to prevent prevalence from increasing. Measuring the rate at which new cases occur over time may be preferable to measuring changes in prevalence (proportion infected at a point in time) because the former may be an earlier and more sensitive indicator of management effects in these cases.

Implementation of Treatments

Each jurisdiction will need to decide which treatments to apply. Some strategies may not be feasible or acceptable within a given jurisdiction. Others already may be in place as part of current deer management practices. Due to the seriousness of the problem and resources available, we also recognize that various combinations of treatments might be applied in a single focal area. The latter approach could be useful in determining whether we can suppress CWD transmission and spread, but teasing apart the individual treatment effects may require further assessment. Under this approach, one could back off on each treatment over time to evaluate the effects of individual treatments. Alternatively, each treatment could be applied independently given what is deemed most feasible to implement. Minimally, various concurrent management practices within an area should be recorded so added sources of variation can be considered.

Target demographic

Because CWD prevalence varies by host age and sex in mule deer, comparisons of prevalence over time are best made within a single sex and age class. There are two considerations for choosing a target demographic: (1) proportional changes in prevalence are easier to detect (i.e., require fewer samples) at a higher starting prevalence (see sample size table, p14) and (2) the target demographic should be the age/sex class most likely to respond, in terms of prevalence, to the experimental treatment. Adult males (≥ 2 yrs old) tend to exhibit the highest prevalence and are consistently harvested in most jurisdictions, and thus may be the most suitable target demographic in most cases. However, the targeted harvest (e.g., winter range or disease focus) and point source reduction management scenarios may be, in certain situations, more likely to have a pronounced effect on prevalence among females. In areas with high prevalence among females, that demographic may be the more important management focus. It would be ideal to measure prevalence across multiple age and sex classes, but because of large sample size needs it likely will be most practical to focus on one target demographic within a given experiment.

Regardless of the metric selected, the same metric should be used before and after treatment for both treated and control units within an experiment.

Communication

The success or failure of any CWD management activity is grounded in effective communications. No one agency or jurisdiction can solve this issue nor tackle it effectively in isolation. It is difficult to portray the significance of an insidious, slow-moving, exotic disease with clinical signs that mimic other problems and population effects that take decades to reach detectable levels. Specific to CWD, a wide range of social, political, recreational, and economic factors also affect overall acceptance of disease control actions, regardless of proposed activity. Thus for success of the management initiatives herein, it is essential to adopt a shared communication approach and offer consistent messages regarding the disease, the concerns, and the wisdom in taking a regional perspective.

Management agencies must be open and realistic when discussing CWD. This includes acknowledging that there are many unknowns when it comes to affecting population change in the dynamics of CWD transmission and spread. However, the alternative of unlimited spread leading to reduced populations seems far more unacceptable and contrary to wise stewardship of primary native herbivores (cervids) across multiple landscapes. And while not proven, there is always the spectre of potential human health aspects that supports actions to curb the rate at which CWD builds in hunted populations and to thereby reduce or minimize human exposure to the CWD agent.

A detailed communications plan is beyond the scope of the current document. However, agencies that undertake disease control are strongly advised to build such a plan in conjunction and coordination with other agencies undertaking CWD control activities in the West. It is important to have similar messages that justify the need, validate the approach, and commit to long term delivery and evaluation of the efforts.

Site Selection Considerations

(Common elements to facilitate cross-jurisdictional comparison)

The underlying adaptive management framework includes a systematic approach for learning from management outcomes over time. This approach is essentially equivalent to the scientific method of hypothesis formulation and hypothesis testing. Results are used not only in evaluating the hypothesis, but also to gather new data directing future management. As a result, agencies looking to participate in this adaptive management venture may consider basic universal criteria for site selection and evaluation of management to facilitate cross-jurisdictional comparisons.

As such, we offer the following elements as common minimum criteria for site selection for any of the CWD management strategies outlined in this document or for new strategies not yet identified. Collection of information beyond the minimum criteria may be desirable to interpret why a manipulation is or is not successful. Additional recommended but less critical elements are italicized.

Manipulation commitment	<p>Commitment of a minimum of 5 years after sustained treatment application to assess the effects of management on response metrics.</p> <p>Ideally, strategies will be evaluated for at least 10 years to account for the length of time for one generation.</p>
Starting CWD prevalence	<p>Detecting changes in prevalence will be most feasible in areas where starting prevalence is 10% or greater in the target demographic (e.g., adult male mule deer). This is because sample sizes needed to sufficiently measure an effect may become prohibitively large where starting prevalence is already low.</p> <p>In low prevalence study areas (<10%), measuring the new infection rate or some other metric (e.g., number of new foci detected) may be more feasible.</p> <p>Goals may include reducing prevalence, preventing increase, or stabilizing.</p>
Size of manipulation area	<p>Minimum spatial footprint would be a discrete unit that can sustain the proposed manipulation and provide samples sufficient to measure effects of the manipulation. In some cases, these discrete units might be described by a herd or game management district or unit. In other situations, they may encompass a portion of, or multiple hunt areas.</p> <p>Consideration should be given to drawing boundaries that minimize immigration/emigration rates and facilitate the consistent application of experimental manipulations.</p>
Frequency of disease surveillance	<p>Select areas where disease surveillance is feasible.</p> <p>Pre-manipulation surveillance: An adequate estimate of CWD prevalence is needed at the beginning of experimental management. This could be done with existing surveillance data if sample size goals have been met or be done through directed surveillance prior to or in the first years of implementation. Because CWD prevalence changes relatively slowly over time and sample size needs can be quite large, pooling data collected over 2-3 years may be necessary to achieve adequate sample sizes.</p> <p>During manipulation surveillance: Depending on existing infrastructure and agency-specific goals, annual or biannual surveillance may be considered throughout the period of manipulation.</p>

Management tracking	Efficacy of the prescribed management strategy tracked annually to determine whether the intended goal of the experimental manipulation is being met. For example, if the management goal is to harvest 30% of males annually, actual male harvest and some index of their relative abundance should be estimated annually.
Population & CWD metric monitoring	<p>Adequate population or herd subunit monitoring data are necessary to complement disease surveillance. At a minimum, this should include:</p> <p>Annual host population estimates and post-harvest buck:doe:fawn ratios, harvest location, estimated age, sex.</p> <p>Ideally, annual population data should be available for at least 3 years prior to implementation to provide population background and relative factors that may have contributed to the current situation.</p> <p>Where necessary, age of sufficient subsample of harvested animals may be used.</p> <p>Baseline estimate of CWD prevalence or occurrence/distribution in sympatric cervid species is recommended, especially for those with highly overlapping ranges of the target population.</p>



Healthy-looking mule deer with CWD

Candidate Disease Management Strategies

Reduce Artificial Points of Host Concentrations

Hypothesis: Reducing repeated deer visitation to artificial concentration points should reduce localized environmental contamination and transmission.

Goal: Identify consistently available, artificial point-sources of food/minerals/water causing deer to aggregate (e.g., leaky grain bins; grain bags; stack yards, artificial feeders or feeding stations, mineral bins) and work with producers, landowners, land managers, and Department of Agriculture to mitigate point-sources and reduce the density of deer at these point-sources within the study area.

Examine the effects of manipulating the density of these point-sources of food on CWD metrics. In addition to outright removal of point-source attractants, approaches for reducing cervid aggregations/visitation might include hazing, fladry, fencing, other modifications for excluding cervids, regulatory changes or enforcement, etc., depending on the specific nature of attractants within a given area.

Prospective Manipulations: Identify treatment and control hunt districts with relatively high densities of point-source attractants and quantify the density. At least 3 winter aerial surveys, conducted annually, supplemented by but not limited to ground counts may be needed to identify and quantify point-source attractants and estimate the number or proportion of deer visiting these attractants. Treatments should include a target removal of $\geq 65\%$ of these attractants within the larger study area in a manner to reduce overall density of attractants within the study area. Continuing aerial/ground surveys will be needed to measure compliance with the reduction/elimination of point-sources of food/minerals and to estimate the number or proportion of deer visiting any remaining point-source attractants within the study area. We recommend initially monitoring the treated sites to document how long until mule deer (and other susceptible species') visitation stops.

Harvest Management

Hypothesis 1: Increasing harvest on the segment of the population that is most likely to be CWD positive should result in reduced disease prevalence and subsequent transmission.

Hypothesis 2: Because male deer harvested later in the season (post rut) appear more likely to be CWD positive, harvesting males later in the season will reduce prevalence.

Hypothesis 3: If significant transmission occurs from animal-animal contact during breeding, then focusing harvest after the rut should remove animals sooner after infection and reduce transmission.

Goal: Increase male harvest, bias harvest toward infected males, and/or shift or maintain timing of harvest to post rut. These manipulations can be applied either individually or in combination. Maintain female harvest at the same level during the assessment.

The manipulation requires a significant increase over the current male harvest level. At minimum, agencies should consider an increase of at least 10 percentage points over the current buck harvest level (e.g., an increase from 20% to 30%). Modeling suggests a buck harvest level of $\geq 30\%$ may be most effective to reduce prevalence. Multiple harvest levels need to be evaluated because the



Mule deer feeding near leaky grain bins

minimum level to effect a reduction in prevalence is unknown. Also, this strategy should be replicated at multiple levels of CWD prevalence to evaluate whether efficacy is dependent upon disease intensity. Therefore, management agencies should coordinate efforts in evaluating this strategy to allow for replication and comparison of efficacy in different populations.

Similarly, assessing the role of harvest timing would depend on shifting all or a significant proportion of the male harvest to a time period after the mule deer breeding season ends. Measuring changes in infection rate or rate of new infection may be undertaken depending on the situation and underlying mechanism of interest.

Prospective manipulations:

Increase buck harvest

- Baseline treatment where prevalence is 10–20% is to increase harvest from < 20% to at least 30%.
- As feasible, evaluate >1 harvest level, particularly in range of 30% to 50%.
- Ideally, male harvest of 30%, 40%, and 50% or more all should be evaluated.
- In areas of high prevalence or where otherwise desired to meet herd or population objectives, concurrent or independent assessment of doe harvest as a tool for CWD suppression may be warranted under guidelines similar to those above.

Shift timing of harvest

- Shift timing of male harvest to include post-breeding. (Exact timing might differ based on latitude, agency logistics, breeding season in the region, etc.) This could be done either in conjunction with increased harvest or as a stand-alone treatment.

Harvest Targeting Disease Foci

Hypothesis: Aggregation of deer (e.g., on winter range) facilitates CWD transmission. Selectively removing animals in concentrated areas where CWD is known to occur may reduce prevalence and transmission.

Goal: Develop a harvest strategy that builds on ongoing harvest or other surveillance programs to maximize removal of infected individuals and reduce rate of new infections.

CWD is clustered on the landscape and appears to reflect social interactions presumably related to higher contact rates in related matrilineal groups, transmission from doe to fawn, and post-rut bachelor groups. Bachelor and mixed sex/age winter groups, particularly aggregates of does and their extended relatives, are thus a potential source of increased transmission. Removing deer around locations of known CWD-infected animals has been shown to remove proportionally higher CWD-infected animals than in the hunter-harvest. A targeted harvest strategy uses surveillance data to identify areas

Mule deer winter group



where harvest will remove deer more likely to be infected. Harvest timing year to year should be consistent and locations need to be geographically defined for license validation.

Prospective Manipulations:

Fall harvest

Deliver standard fall harvest. Use previous surveillance data built on current combined male and female harvest to map cumulative locations of infected individuals.

Targeted deer removals

In the vicinity of areas or foci of known CWD occurrences identified through surveillance, use later seasons or the next year's harvest to target removal of potentially-infected deer. Ideally, social groups will be removed regardless of sex/age composition. Instruments of harvest could include quota license, party/partner licenses, damage control license, agency or non-agency sharpshooters or a combination thereof. In areas of relatively recent

disease introduction or spread, emphasis on rapid response of targeted removal such as on winter ranges may be preferable. Depending on timing of movements and harvest seasons, this may require additional movement data to accurately target areas for later seasons. In areas where CWD is well established or winter seasons are not feasible, targeted removal in defined geographic foci may be accomplished during the following year's harvest or other seasons that fall within standard harvest management practices.



Tagging a mule deer

Evaluation and Assessment

To evaluate the efficacy of management actions and to facilitate comparisons across jurisdictions, at minimum, we recommend the following:

Metric of disease intensity

Prevalence, force of infection, and incidence are the metrics of disease intensity most relevant to the measure of CWD infection intensity within a population over time.

- Prevalence is defined as the proportion of test-positive animals within a reference population sample over a specified period of time.
- Force of infection is the probability, over a short period of time, that an uninfected animal contracts an infection.
- Incidence is defined as the number of new cases of disease in a population at risk over a defined period of time.

Prevalence is the easiest of the three metrics to measure. However, given the long course of CWD infection, prevalence also is the least sensitive or slowest to respond to changes in disease dynamics.

Force of infection (or the estimated number of new cases per year) requires collecting detailed sex and age-specific prevalence data, but is more sensitive to changes in transmission rates. Incidence gives the best information to track changes in rates of disease transmission, but it requires repeated live capture and sampling of individually marked animals, thus increasing costs and logistical complexities. At minimum, we recommend that jurisdictions track prevalence, but if sex and age-specific prevalence data are available (requires taking a tooth or using wear patterns to obtain a precise age estimate) then force of infection could be considered.

We offer the following elements as common minimum criteria for evaluation of any of the three primary CWD management strategies outlined in this document. Collection of information beyond the minimum criteria may be desirable to interpret why a manipulation is or is not successful in meeting the goals of the program. Additional recommended but less critical elements are italicized.

Frequency of disease surveillance	One post-treatment sampling effort (beginning year 6 or 11) with sample sizes determined from the table below. These sampling efforts may span up to 3 years each to achieve target sample sizes. Annual or biennial prevalence estimates also could be measured throughout the treatment period.
Management tracking	The prescribed management strategy should be sufficiently measured to determine if the manipulation goal is being met.
Age-specific prevalence	Collecting age-specific disease data would allow for evaluation of force of infection and may be a more sensitive metric to evaluate change in transmission. This would require an age estimate for each animal sampled.

Sample sizes

Sample size calculations depend on the estimated magnitude of the treatment effect, a specified confidence level (i.e., confidence = $1-\alpha$; α typically = 0.05, but jurisdictions might consider using α = 0.1 or even α = 0.2 for these experiments to identify potentially useful strategies), and statistical power (i.e., power = $1-\beta$; β typically = 0.2). Assuming 95% confidence and 80% power, sample sizes needed for each study population, before and after treatment, to detect differences among specified prevalences (P1 vs. P2) are as follows:

	P2 = 0.025	P2 = 0.05	P2 = 0.1	P2 = 0.2	P2 = 0.3	P2 = 0.4	P2 = 0.5
P1 = 0.025	NA	906	163	50	28	18	13
P1 = 0.05	906	NA	435	76	36	22	15
P1 = 0.1	163	435	NA	199	62	32	20
P1 = 0.2	50	76	199	NA	294	82	39
P1 = 0.3	28	36	62	294	NA	356	93
P1 = 0.4	18	22	32	82	356	NA	388
P1 = 0.5	13	15	20	39	93	388	NA

Sample sizes were calculated using power.prop.test in Program R.

For example, if we had existing information that suggested that CWD prevalence was 20% (P1) among adult male mule deer and we anticipated that our management efforts would reduce prevalence to 10% (P2) then we would need approximately 199 samples before and after treatment to detect such an effect with 95% confidence and 80% power and ~155 samples to detect such an effect with 90% confidence. Sample size needs increase for lower prevalence and smaller effect sizes.

Small or finite population sizes should reduce these estimated sample size needs, and such statistical adjustments may be considered in some situations. However, the values listed in the table above may still remain minimum targets given that the clustering of disease, clustering of animals, and biases inherent in convenience sampling (i.e., hunter harvest) will increase the variance around prevalence estimates and reduce our power to detect differences in prevalence over time. In cases where management plans call for use of alternative metrics, the sample size requirements for such metrics should be calculated as part of the planning process.



Acknowledgements

We thank the Alberta Prion Research Institute for hosting the 2016 Northern Plains Ecosystem Chronic Wasting Disease Workshop in Alberta. Discussions from that workshop directly resulted in the development of this concept and ultimately led to the formation of a self-appointed “Ad hoc Working Group on Chronic Wasting Disease Management in the West” (M. E. Wood, M. J. Pybus, E. S. Almberg, K. Mehl, T. K. Bollinger, E. Merrill, M. Ball, M. W. Miller) that drafted the original version of these recommendations. We also thank Alberta Environment and Parks, Edmonton, particularly graphic designer Gwen Edge, for preparing the final design and layout of this document.

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